Assessment of the textural variation of iced stored *Anabas testudineus* (Bloch, 1792) muscle tissue with emphasis on their collagen and myofibrillar protein content

Treesa Varghese^{1,2} · Saleena Mathew¹

Revised: 3 March 2017 / Accepted: 12 May 2017 / Published online: 30 May 2017
© Association of Food Scientists & Technologists (India) 2017

Abstract Post-mortem biochemical and physiological changes of climbing perch (*Anabas testudineus*) muscle evaluated during iced storage of 18 days compared with muscle protein content. Changes in the protein fractions, rigor index, pH value, water holding capacity, expressible water content, cook loss, textural parameters, and histochemical properties of the post mortem fish muscle were studied. The whole fish were in full rigor condition till fifth day of storage. Initial muscle pH value of 6.97 was dropped to 6.90 when the fish reached in full rigor condition, this then increased to 7.10 on the final day of storage period. The myofibrillar protein decreased with an initial value of 29.76% and a final value of 13.49%. 40.27% decrease in total collagen content was observed during the storage period. The water holding capacity of fish muscle decreased when the fish muscle entered in post rigor stage while cook loss and expressible water content were significantly increased. The histochemical studies and textural profile analysis of fish muscle proved that the degradation of both collagen and myofibrillar protein induces the post-mortem tenderization and the resultant quality deterioration of iced stored *Anabas testudineus* fish.

Keywords Post-mortem · Texture · Collagen · Myofibrillar protein

Introduction

The climbing perch (*Anabas testudineus*) is a hardy fish species abundant in tropical fresh waters of South East Asian Countries. Owing to its fine flavor and prolonged freshness out of water *A. testudineus* is one of the highly esteemed food fish which is organoleptically preferred and fetch high market prices in many parts of India. The delicate taste and flavor, makes the species an important staple food fish in the subcontinent. Despite of its nutritive value and consistent availability in live condition, the post-harvest management and processing of *A. testudineus* in India is still deprived. Due to the increasing demand of these high quality fresh water fishes, there is an obvious need for development of new technologies and efficient fish preservation methods which permit shelf life extension (Ahmed et al. 2009). The information on the post-mortem changes of *A. testudineus* under various storage conditions is scarce.

During icing or chilled storage of fish, several chemical changes are reported to take place in fish muscle which consequently affects the meat quality (Gaarder et al. 2012; Kaale and Eikevik 2013). The initial state of freshness is gradually transformed by the post mortem-degradation processes in fish muscles. The solubility characteristics of collagen and myofibrillar proteins is considered as one of the most important quality indices of fresh and processed fish meat. The conformation of proteins, which is related to the environment to which the protein is exposed, plays an important role in defining the adequacy of storage conditions (Ghelichpour and Shabanpour 2011). The protein solubility depends on many intrinsic factors such as protein structure, pH of fish muscle, ionic concentration etc. Even though, the pH-solubility relationship of proteins has been extensively studied for many commercial fish and fishery

✉ Treesa Varghese
treesanv@gmail.com

¹ School of Industrial Fisheries, CUSAT, Kochi, Kerala, India

² School of Biosciences, MACFAST, Tiruvalla, Kerala, India

products (Geirsdottir et al. 2007; Bourtoom et al. 2009), very little attention has been given to tropical fresh water fishes such as *A. testudineus*. The texture of the muscle is another important sensory characteristic of fresh fish which directly influence the consumer preference. Fish meat is generally expected to be firm but tender, and remain luscious. The deterioration of texture takes place during postmortem changes and are often associated with protein denaturation. The textural post-mortem changes seen in fish are results of breakdown of myofibrillar proteins, extracellular matrix and collagen fraction of muscle (Andersen et al. 1997). Texture-related problems such as softening and gaping will make the fish unfit for processing and consumption.

The water content and its distribution in fish flesh will influence the textural and sensory properties. Hence the water holding capacity may be considered as an important quality characteristic of raw fish. Besides the water holding capacity, the expressible moisture content which is the actual loss of the moisture during the application of pressure, gives different information about physical properties of fish muscle under different conditions of storage. It was previously demonstrated that the water binding capacity of the proteins shows noticeable decrease due to the increase in moisture content of meat (Aaslyng et al. 2003). During the process of cooking, a significant decrease in the level of moisture and fat were reported for fresh water fishes (Dhanapal et al. 2012) and fish fillets (Aberoumand 2014).

Storage of fish in ice is a normal procedure for preserving high quality of fresh fish from the past decades; even though, storage in ice seriously affect the physico-chemical properties of fish muscle and hence final consumer acceptance. This information triggered an enthusiasm to look at the effect of ice storage on physicochemical properties with respect to the changes in protein fraction and final quality of *A. testudineus*. In this study, the effects of storage conditions on change in protein fractions, pH, water holding capacity, expressible water content, cook loss etc. of the post mortem fish muscle were studied during 18 days storage in ice then tried to compare with progress of rigor mortis and textural variation.

Materials and method

Collecting and handling sample

Fish samples were procured from a local fish market, Tiruvalla, Kerala, India. They were caught by the cast net from the nearby paddy fields by fishermen and transported to the market and later transferred to the laboratory in a water container to immerse the live fish. The *A. testudineus* was slaughtered (stunned by a blow to the head), kept in

plastic boxes with ice (ice:fish is 0.5:1) and stored in a refrigerated chamber (4 °C) for 18 days. During storage, ice was periodically added and replenished every 12 h. During storage, fish were randomly taken at days 0, 1, 3, 5, 7, 9, 12, 15 and 18 for analysis. Muscle between the gills and the dorsal fins were used for analyses in triplicates.

Analysis

Rigor index of the whole fish was determined according to the method of Bito et al. (1983). The pH value was determined by homogenizing one gram of pooled fish muscle in 10 mL of distilled water with a pH meter (ELICO's pH Meter LI 127).

Water holding capacity (WHC) was determined according to the method described by Borresen (1980) with slight modifications. 2 g of filleted sample was centrifuged at 4500 rpm for 15 min by keeping a filter paper at the bottom of the centrifuge tube to remove the water content from fillet. After centrifugation, the fillet were weighed again, and the difference between before and after centrifugation was calculated. The moisture content was determined, and used to calculate the water holding capacity. The WHC expressed as % as the ratio of water compared to the water content in the in the sample.

Expressible water content (EWC) was determined according to the method of Benjakul et al. (2003), was calculated as percentage of sample weight.

Cook loss was determined according to a modified version of the method described by Borresen (1980). Homogenised sample (2 g) from each individual were put in container with a filter, incubated at 100 °C for 15 min and then left to thoroughly cool down in ambient temperature. Then the containers were weighed. Cook loss was calculated as the percentage of reduction of the cooked sample compared with the raw sample and is presented as % lost sample.

Protein fractions were extracted from the fish muscle according to the method of Devadasan and Nair (1970). Amount of protein fractions in the extract was determined quantitatively in terms of nitrogen using micro-kjeldhal method.

Instrumental texture profile analysis was conducted by using Texture Analyzer (Lloyd Instruments, UK, model LRX PLUS) and Nexygen software (Lloyds Instruments). Flat-faced cylindrical probe of 50 mm diameter equipped with a load cell of 50 N and a test speed of 12 mm/min with a trigger force of 0.5 Kgf compressed the bite size piece (2 cm³) twice in a reciprocating motion, imitating the mouth action. Samples were subjected to a double compression of 40%. From the force–time plot, hardness 1—after first compression (N), hardness 2—after second compression (N), cohesiveness, springiness (mm), chewiness (N mm) and stiffness (N/mm) were evaluated.

Histochemical evaluation of muscular pattern of the fish muscle tissue performed using the following procedure. Iced samples of *A. testudineus* were cut into small piece of blocks and fixed overnight in using formalin fixative, followed by dehydration in serially diluted alcohol (70–96%). Dehydrated sample was then treated with xylene to remove alcohol content and was embedded in paraffin wax (melting point 60 °C). Paraffin embedded sample were cut into sections of 8 µm using rotary microtome. Double staining using Haematoxylin stain and Eosin stain was performed. Myofibrils were stained yellowish orange and collagen to blue and were observed under compound light microscope and photographed.

Statistics analysis were performed with the SPSS (version 10). Descriptive statistics (mean, standard deviation), one-way ANOVA, multiple comparison with the Tukey test. Significance level was set at 0.05.

Result and discussion

Fresh water fish are highly susceptible to rapid quality loss during post-mortem storage. Storage condition and time have great impact on its quality and its stability dependent on the physico-chemical composition. Figure 1 showed change in pH and rigor index of iced stored *Anabas testudineus*. The whole fish showed rigor index value of 86.44% on the first day of storage and was increased to 88.51% by 3rd day of storage, value was stable till the 5th day. The pH value of fish muscle at zeroth day was close to the neutral value (6.97) and was dropped to 6.90 by 1st day of storage ($p < 0.05$). As the fish proceeds through the post rigor stage, an increase in muscle pH was noticed and is increased to 7.10 by 18th day of storage in ice. The result obtained is in good agreement with Ruiz-Capillas and Moral (2001), Yongswawatdigul and Park (2002), Wang et al. (2003), Hultmann and Rustad (2004). Change in pH value is closely related to rigor index. Slight decline in pH

during the initial stage of incubation was due to the accumulation of hydrogen ion liberated by the breakdown of adenosine nucleotides and its metabolites in fish muscle and was strongly related with lactate accumulation (Nazir and Magar 2006). Rate of formation of lactic acid is roughly proportional to the amount of ATP produced by anaerobic glycolytic system and the amount of lactic acid accumulated was significantly dependent on the glycogen reserve at the time of death (Lougovois and Kyrana 2005). Accumulation of lactic acid in post-mortem stage was greatly influenced by the degree of struggle before death and storage temperature (Iwamoto et al. 1987). This was due to the accumulation of basic compounds like amine arising from breakdown of protein, lipids and carbohydrates by autolytic and microbial enzymes, serve as substrate for the for spoilage causing bacteria (Ruiz-Capillas and Moral 2001; Ozogul et al. 2008).

A significant ($p < 0.05$) difference for water holding capacity, expressible water content and cook loss of fish muscle were observed (Fig. 2). On the other hand, water holding capacity decreased from 70.54 to 54.90%, whereas expressible water content got increased from 12.01 to 25.68%. Cook loss also found to be increased from 7.35 to 35.27% of the total tissue weight. This changes in water holding capacity, expressible water content and cooking loss is closely related to the muscle pH, proving that drop in pH value during post mortem storage act as major causative factor in water loss from the tissue. Warriar et al. (1975) reported that 2/3rd of loss in the water holding capacity of the fish muscle tissue could be due to the breakdown of ATP molecules and 1/3rd could be due to the decrease in pH level. Hermansson and Lucisano (1982) reported that amount of water released from the sample was found to be greatly influenced by the water holding capacity and by the magnitude of micro structural change that is a function of the textural strength of the sample. Sato et al. (1991) reported that assessment of water holding capacity to be a good indicator for fish quality evaluation,

Fig. 1 Postmortem changes in rigor index and pH in the muscle of climbing perch (*Anabas testudineus*) stored at iced condition during 18 days

Fig. 2 Postmortem changes in water holding capacity, expressible water content and cook loss in the muscle of climbing perch (*Anabas testudineus*) stored at iced condition during 18 days

reduction in WHC has a direct relation with loss of texture properties.

Table 1 depicts that there was a change in protein fractions during the ice storage of 18 days in *A. testudineus*. Muscle showed a slight variation in the sarcoplasmic protein content, only up to 1.46% reduction were observed during the incubation period ($p < 0.05$). The result obtained shows that a gradual decrease in myofibrillar protein and is decreased from 29.76 to 13.49% ($p < 0.05$). Considering denatured protein, its concentration increased from 35.23 to 56.82% on the last day of storage in ice ($p < 0.05$). This result was in good agreement with Pacheco-Aguilar et al. (2000), Hossain et al. (2005). Total collagen content in the fish muscle also found to be very unstable and was decreased over storage time (40.27%, $p < 0.05$). Additionally, a slight increase in total collagen content was noticed till the 5th day of incubation. Many studies reported that the collagen content slightly decreased during ice storage (Kamal et al. 2000; Suarez et al. 2005). Ando et al. (1995) reported that the structural change in the collagen fibrillar network is significantly related to the post-mortem tenderization.

Textural profile of *A. testudineus* stored at iced condition for 18 days also showed some variation (Table 2). Hardness represents the peak force required to compress the test sample. Decrease in both values of Hardness 1 and Hardness 2 might be due to the breakdown of fibrous proteins of fish muscle by the proteolysis caused by autosomal and microbial enzymes. Viji et al. (2014), studied the quality characteristics and shelf life of sutchi cat fish (*Pangasianodon hypophthalmus*) steaks during refrigerated Storage. The highest value for stiffness was noticed on the third day of incubation, it was 26.9702 N/mm and is gradually decreased to 11.9886 N/mm by 18th day of storage. Result indicated the whole fish reached in full rigor condition by third day of incubation in ice and then it entered in post rigor stage. Suarez et al. (2005) reported that firmness of fish is directly correlated with the collagen content in muscle tissue. Softening phenomenon in fish muscle is primarily due to the weakening of pericellular tissue (Sato et al. 1997). Azam et al. (1989) also studied that a significant level of softening of rainbow trout fillet incubated at iced stored condition for 15 days. Springiness is the elastic or recovering property of the fish muscle during compression. A change in

Table 1 Change in protein fractions in the muscles of climbing perch (*Anabas testudineus*) stored at iced condition during 18 days

Days in ice	Sarcoplasmic protein (%)	Myofibrillar protein (%)	Denatured protein (%)	Total collagen (%)
0	22.5768 ^{a,b} ± 1.4061	29.7561 ^c ± 0.8134	35.2260 ^a ± 2.1873	12.4411 ^c ± 0.0322
1	23.5547 ^{a,b} ± 0.2673	28.6839 ^c ± 1.0721	35.1636 ^a ± 0.7543	12.5978 ^c ± 0.0505
3	23.7562 ^{a,b} ± 0.2153	25.3676 ^d ± 0.4451	38.2133 ^{a,b} ± 0.2655	12.6628 ^c ± 0.0357
5	23.4425 ^{a,b} ± 0.4108	23.0727 ^{c,d} ± 0.2076	41.0536 ^{b,c} ± 0.1107	12.4312 ^c ± 0.0925
7	24.5799 ^{a,b} ± 0.9722	23.79875 ^{c,d} ± 0.3501	38.7039 ^{a,b} ± 2.4017	12.9173 ^c ± 1.0793
9	25.5648 ^b ± 0.0229	22.93415 ^{c,d} ± 0.1506	39.9854 ^b ± 0.7858	11.5156 ^{b, c} ± 0.9135
12	24.0226 ^{a,b} ± 1.0659	21.80788 ^c ± 0.4529	43.7144 ^c ± 1.3412	10.4550 ^b ± 0.7283
15	24.4885 ^{a,b} ± 2.6644	17.35211 ^b ± 2.0112	48.2469 ^d ± 1.6453	9.9123 ^b ± 0.9922
18	22.2475 ^a ± 0.8386	13.49367 ^a ± 1.2929	56.8246 ^e ± 0.9887	7.4341 ^a ± 0.5344

Values are given as mean ± standard deviation from triplicate determinations. Different superscripts in the same column indicate significant differences ($p < 0.05$)

Table 2 Post-mortem textural profile in the muscle of Climbing perch (*Anabas testudineus*) stored at iced condition during 18 days

Days in ice	Hardness1 (N)	Hardness2 (N)	Cohesiveness (N)	Springiness (mm)	Gumminess (N)	Chewiness (N mm)	Stiffness (N/mm)
0	14.5541 ^{de} ± 0.9363	4.6424 ^c ± 0.0612	0.4667 ^{b,c} ± 0.0040	0.6845 ^{d,e} ± 0.0050	0.5942 ^{f,g} ± 0.0050	0.2157 ^c ± 0.0591	22.5396 ^d ± 0.0019
1	15.2189 ^e ± 0.2098	4.8758 ^{c,d} ± 0.0387	0.4197 ^{a,b} ± 0.0075	0.6703 ^{c,d} ± 0.0015	0.5393 ^f ± 0.0237	0.3069 ^d ± 0.0002	26.8575 ^f ± 0.0006
3	15.3287 ^e ± 1.6545	5.2220 ^d ± 0.3905	0.4314 ^{a,b} ± 0.0495	0.7414 ^e ± 0.0126	0.6138 ^g ± 0.0232	0.3706 ^{d,e} ± 0.0212	26.9702 ^{e,f} ± 0.0093
5	14.2019 ^{de} ± 1.7118	4.9945 ^{c,d} ± 0.1718	0.6060 ^c ± 0.0400	0.7222 ^d ± 0.0301	0.5805 ^{f,g} ± 0.0276	0.4197 ^c ± 0.0376	16.8507 ^c ± 0.0144
7	12.6967 ^{cd} ± 0.2657	3.7853 ^b ± 0.3905	0.3520 ^{a,b} ± 0.0495	0.4602 ^{a,b} ± 0.0126	0.4618 ^e ± 0.0232	0.2284 ^c ± 0.0212	22.6681 ^{d,e} ± 0.0093
9	10.9108 ^{bc} ± 0.8251	3.2685 ^b ± 0.1203	0.3687 ^{a,b} ± 0.1184	0.5009 ^b ± 0.0351	0.3755 ^d ± 0.0490	0.1971 ^{b,c} ± 0.0051	19.4603 ^{c,d} ± 0.0177
12	9.5153 ^b ± 1.7118	2.7223 ^a ± 0.1718	0.2902 ^{a,b} ± 0.0400	0.4485 ^{a,b} ± 0.0303	0.3040 ^c ± 0.0276	0.1304 ^{a,b} ± 0.0376	15.8857 ^{b,c} ± 0.0144
15	5.8321 ^a ± 1.7873	2.3261 ^a ± 0.8420	0.3030 ^{a,b} ± 0.1501	0.4283 ^a ± 0.21374	0.2069 ^b ± 0.0848	0.1186 ^a ± 0.1674	11.4875 ^a ± 0.0079
18	5.1867 ^a ± 0.2657	2.2986 ^a ± 0.14621	0.4295 ^a ± 0.0193	0.4142 ^c ± 0.0341	0.1265 ^a ± 0.0251	0.1176 ^a ± 0.0277	11.9886 ^{a,b} ± 0.0023

Values are given as mean ± standard deviation from triplicate determinations. Different superscripts in the same column indicate significant differences ($p < 0.05$)

springiness values was observed ($p < 0.05$), indicating losing of its elasticity during storage. This result was in good agreement with Viji et al. (2014) in sutchi cat fish (*Pangasianodon hypophthalmus*) Steaks during refrigerated storage and Manju et al. (2007) in pearlspot (*Eetroplus suratensis*) during chill storage. Presence of myosin contribute elasticity to the fish gel network (Chan et al. 1995). Chewiness also significantly ($p < 0.05$) changed in response to storage condition. Cohesiveness gives an indication of how well the samples withstand the deformation ($p < 0.05$).

Histochemical evaluation of tissue provides a demonstrated idea regarding the textural changes along with degradation of myofibrillar and collagen fibers (Fig. 3). From the result it is clear that post mortem gaping phenomenon was a byproduct of disintegration of connective tissue collagen fibers which connect the individual myocommata. As in incubation time proceeds, disappearance of myofibrillar protein also detected in the fish muscle tissue. The result obtained also supported by Yathavamoorthi et al. (2010), who stated that textural properties of fish muscle mainly associated to the quality of myosin in the myofibrillar protein. It also noticed that that a minimum repulsion between proteins was observed at acidic pH, subsequently the water holding capacity was high. Water holding capacity and expressible water content significantly affect the tenderness of the fish muscle. Study proving that the pH induced protein aggregate formation decreases total surface area of the fibrous proteins, resulting in partial denaturation followed by a reduction in water holding ability. The irreversible formation of actomyosin cross bridge in in-rigor condition reduces the water binding capacity of the myofibrils. Hike in expressible water content during incubation time indicates loss of affinity of fish muscle for water in accordance with a decline in water holding capacity. Because of denaturation and increased proteolysis and subsequent loss of structural integrity in the muscle alter ability of proteins water retention capacity.

Increased cooking loss directly related with the protein functionality in muscle tissue. Upon heating denatured protein undergo thermal denaturation too, leading a severe aggregation of the same. Thus the present study specified that denaturation of myofibrillar protein and collagen (by aggregation and/or hydrolysis) could have occur in the muscles of *A. testudineus* fish during the period of storage had negatively affected its textural properties, which will negatively influence both to processing industry and final consumer. Further studies are needed to understand the proteolytic process of protein fractions of this species muscle by doing SDS- PAGE during its chilled storage.

Fig. 3 Histological images of meats from climbing perch (*Anabas testudineus*) with different iced storage time

Conclusion

The post mortem studies of iced stored *Anabas testudineus* indicated that paramount post-harvest handling procedures could be beneficial for prevention of endogenous quality deterioration. The physico-chemical parameters adapted in this study demonstrated their importance in determining the overall quality of the fish muscle. Quantitative changes in protein fractions greatly influences the textural and histochemical features of *A. testudineus* fish muscle. In the meantime, the rigor index was changed with respect to the storage time, this can be used as a sufficient visual indicator for assessing the post mortem fish muscle tenderization followed by loss of freshness while kept in ice. Based on this fact, the present study is strongly suggested that the local fishermen in Kerala may perhaps implement more powerful handling procedure to improve the shelf life of the *A. testudineus*.

References

- Aaslyng MD, Bejerholm C, Ertbjerg P, Bertram HC, Andersen H (2003) Cooking loss and juiciness of pork in relation to raw meat quality and cooking procedure. *Food Qual Preference* 14:277–288
- Aberoumand A (2014) Preliminary studies on nutritive and organoleptic properties in processed fish fillets obtained from Iran. *Food Sci Technol (Campinas)* 34(2):287–291
- Ahmed K, Masudul Hasan M, Alam Jahangir, Ahsan Nazmul, Islam Monirul, Akter MS (2009) Effect of gamma radiation in combination with low temperature refrigeration on the chemical, microbiological and organoleptic changes in *Pampus chinensis*. *World J Zool* 4(1):09–13
- Andersen UB, Thomassen MS, Anna Maria B (1997) Texture properties of farmed rainbow trout (*Oncorhynchus mykiss*): effects of diet, muscle fat content and time of storage on ice. *J Sci Food Agric* 74(3):347–353
- Ando M, Yoshimoto Y, Inabu K, Nakagawa T, Makinodan Y (1995) Post mortem change of three dimensional structure of collagen fibrillar network in fish muscle pericellular connective tissues corresponding to post-mortem tenderization. *Fish Sci* 61:327–330
- Azam K, Mackie IM, Smith J (1989) The effect of slaughter method on the quality of rainbow trout (*Salmo gairdneri*) during ice storage. *Int J Food Sci Technol* 24:69–79
- Benjakul S, Visessanguan W, Tueksuban J (2003) Changes in physicochemical properties and gel-forming ability of lizard-fish (*Saurida tumbil*) during postmortem storage in ice. *Food Chem* 80:535–544
- Bito M, Yamada K, Mikumo Y, Amano K (1983) Studies on rigor-mortis of fish-I. Differences in the mode of rigor-mortis among some varieties of fish by modified cuttings method. *Bull Tokai Reg Fish Res Lab* 109:89–96
- Borresen T (1980) New methods for determination of liquid holding capacity, salt water holding capacity and cook loss in fish muscle (in Norwegian). FTFI Report 663, Tromsø, Norway, pp. 1–7
- Bourtoom T, Chinnan MS, Jantawat P, Sanguandeeul R (2009) Recovery and characterization of proteins precipitated from surimi wash-water. *JFST* 42:599–605
- Chan JK, Gill TA, Thompson JW, Singer DS (1995) Herring surimi during low temperature setting, physicochemical and textural properties. *J Food Sci* 60(6):1248–1253
- Devadasan K, Nair MR (1970) Observations on changes in the major protein nitrogen fraction of prawns and sardines during ice storage. *Fish Technol* VII 2:195–197
- Dhanapal K, Reddy GV, Naik BB, Venkateswarlu G, Reddy AD, Basu S (2012) Effect of cooking on physical, biochemical,

- bacteriological characteristics and fatty acid profile of Tilapia (*Oreochromis mossambicus*) fish steaks. Arch Appl Sci Res 4(2):1142–1149
- Gaarder M, Bahuaud D, Veiseth-Kent E, Mørkøre T, Thomassen M (2012) Relevance of calpain and calpastatin activity for texture in super-chilled and ice-stored Atlantic salmon (*Salmo salar* L.) fillets. Food Chem 132(1):9–17
- Geirsdottir M, Hlynisdottir H, Horkelsson G, Sigurgisladottir S (2007) Solubility and viscosity of herring (*Clupea harengus*) proteins as affected by freezing and frozen storage. J Food Sci 72:376–380
- Ghelichpour M, Shabanpour B (2011) The investigation of proximate composition and protein solubility in processed mullet fillets. IFRJ 18(4):1343–1347
- Hermansson A, Lucisano M (1982) Gel characteristics—water binding properties of blood plasma gels and methodological aspects on the water binding of gel systems. Food Sci 47(6):1955–1959
- Hossain MI, Islam MS, Shikha FH, Kamal M, Islam MN (2005) Physicochemical changes in Thai Pangas (*Pangasius sutchi*) muscle during ice-storage in an insulated box. PJBs 8(6):798–804
- Hultmann L, Rustad T (2004) Iced storage of Atlantic Salmon (*Salmo salar*)—effect of endogenous enzymes and their impact on muscle portion and texture. Food Chem 87:31–41
- Iwamoto M, Yamanaka H, Watabe S, Hashimoto K (1987) Effect of storage temperature on rigor-mortis and ATP degradation in plaice *Paralichthys olivaceus* muscle. J Food Sci 52:1514–1517
- Kaale LD, Eikevik TM (2013) A histological study of the microstructure sizes of the red and white muscles of Atlantic salmon (*Salmo salar*) fillets during superchilling process and storage. J Food Eng 114(2):242–248
- Kamal M, Rahman MM, Yasmin L, Islam M, Nurullah M, Mazid MA (2000) Studies on the postmortem changes in shrimp and prawn during ice storage: II. Biochemical aspects of quality changes. BFRI 4(1):91–96
- Lougovois VP, Kyrana VR (2005) Freshness quality and spoilage of chill-stored fish. In: Riley AP (ed) Food policy, control and research. Nova Science Publishers, New York, pp 35–86
- Manju S, Jose L, Gopal TKS, Ravisankar CN, Lalitha KV (2007) Effect of sodium acetate dip treatment and vacuum-packaging on chemical, microbiological, textural and sensory changes of pearl spot (*Etroplus suratensis*) during chilled storage. Food Chem 102:27–35
- Nazir DJ, Magar NG (2006) Biochemical changes in fish muscle during rigor mortis. J Food Sci 28(1):1–7
- Ozogul F, Özogul Y, Kuley E (2008) Nucleotide degradation and biogenic amine formation of wild white grouper (*Epinephelus saeneus*) stored in ice and at chill temperature (4°C). Food Chem 108:933–941
- Pacheco-Aguilar R, Lugo-Sanchez M, Robles-Burgueno MR (2000) Postmortem biochemical and functional characteristic of Monterey sardine muscle stored at 0 °C. J Food Sci 65(1):40–47
- Ruiz-Capillas C, Moral A (2001) Correlation between biochemical and sensory quality indices in hake stored in ice. Food Res Int 34(5):441–447
- Sato K, Ohashi C, Ohtsuki K, Kawabata M (1991) Type V collagen in trout (*Salmo gairdneri*) muscle and its solubility change during chilled storage of muscle. J Agric Food Chem 39(7):1222–1225
- Sato K, Ando M, Kubota Origasa K, Kawase H, Toyohara H, Sakaguchi M, Nakagawa T, Makinodan Y, Ohtsuki K, Kawabata M (1997) Involvement of type V collagen in softening of fish muscle during short-term chilled storage. J Agric Food Chem 45:343–348
- Suarez MD, Abad M, Ruiz-Cara T, Estrada JD, Garcia-Gallego M (2005) Changes in muscle collagen content during post mortem storage of farmed sea bream (*Sparus aurata*): Influence on textural properties. Aquac Int 13(4):315–325
- Viji P, Tanuja S, Ninan G, Zynudheen AA, Lalitha KV (2014) Quality characteristics and shelf life of sutchi cat fish (*Pangasianodon hypophthalmus*) steak during refrigerated storage. IJAFST 5(2):105–116
- Wang H, Liceaga-Gesualdo AM, Li-Chan ECY (2003) Biochemical and physicochemical characteristics of muscle and natural actomyosin isolated from young atlantic salmon (*Salmo salar*) fillets stored at 0 and 4 °C. J Food Sci 68(3):784–789
- Warrier SB, Gore KMS, Kumta US (1975) Fish muscle structural proteins. Fish Technol 12(1):1–15
- Yathavamoorthi R, Sangar TV, Ravishankar CN (2010) Effect of ice storage and washing on the protein constituents and textural properties of surimi from *Labeo calbasu* (Hamilton, 1822). Indian J Fish 57(4):85–91
- Yongswawadigul J, Park JW (2002) Biochemical and conformation changes of actomyosin from threadfin bream stored in ice. J Food Sci 67(3):985–990